Z-99 BANDWIDTH REQUIREMENTS FOR METAL DETECTORS

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Summary

The bandwidth of a conventional induction sensor can be controlled with the use of magnetic flux feedback. Without feedback the device operates as a tuned critically damped conventional receiver. For a sufficiently high resonant frequency, the sensor output is then nearly proportional to the time derivative of the secondary magnetic field. With massive feedback however, the sensor response is proportional to the magnetic field itself rather than to its time derivative. Here we examine the effects of either approach. For a 37mm diameter steel sphere target we find that with sufficient feedback the secondary field transient can be recovered with minimal distortion. In this case the sensor shows a flat response over four decades of frequency.

Introduction

As land previously occupied by military installations is returned to civilian use, it must be cleared of all unexploded ordinance (UXO) before it can be declared safe for passage. This requirement has spurred much new research and aimed at the development of new metal locators specifically designed for the detection of unexploded buried munitions that range in size from small machine gun ammunition to artillery shells to large deeply buried, but still possibly active, bombs. Of course improved UXO detection is a prime objective but it is equally important to identify the size, shape, and metal content of the object and to discriminate against scrap metal and the effects of magnetic and electric geological inhomogeneities in the ground. Most existing metal locators may be thought of as scaled versions of the electromagnetic (EM) systems that have been used for mineral exploration. The large scale systems used for detecting deep mineral targets have practical constraints on their configurations, power and bandwidth requirements. The small size of the transmitter-receiver (T-R) assembly used for shallow metallic targets however, offer exciting possibilities for a new generation of EM systems optimized for these targets.

The detection and characterization of metallic objects can be considered as a two-step process: location and identification. As demonstrated by Morrison et al. (2002) any bounded metallic object can be represented approximately by three co-located orthogonal magnetic dipole polarizabilities. Using a simple and robust inversion scheme for determining the location and magnitude of the principal polarizabilities of a bounded object it is possible to coarsely identify it using narrow-band spatial data acquired with a number of co-located EM transmitters and a multiplicity of associated receiver sensors. For symmetric targets, the polarizability vector corresponds to the orientation of the body and its components are an indication of the target geometry. To fully identify the target however, i.e. to find its size, actual shape, and composition it is necessary to measure its broadband time or frequency domain response. At this point system bandwidth becomes an important feature of metal detector design and optimization. Narrow band systems reject ambient noise but also can severely distort the target signal rendering it virtually useless for detailed characterization of the target. Wideband systems however require very high transmitter moments in order to allow the extraction of target signals from the ever present cultural and natural EM noise. In this paper we discuss the operation of an EM induction sensor whose bandwidth is variable. Depending on circumstances, the sensor can be tuned and critically damped so that it shows the conventional dB/dt behavior. On the other hand, with the judicious use of feedback, the sensor can be made to have a flat response over many decades of frequency so that its behavior is more akin to that of magnetometer that measures B. In either case the dc target response cannot be recovered.

Wideband sensor

The idea for a sensor with wideband frequency response originated in France nearly forty years ago (Glerc and Gilbert, 1964). As shown below,

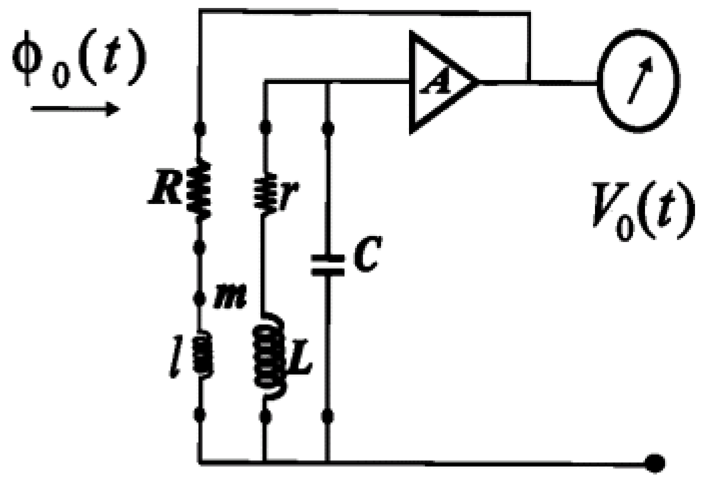

Figure 1. The wideband sensor.

this induction device consists of a principal winding denoted by its inductance “L” and resistance “r”. It is tuned by the capacitance “C” to a central frequency “ω_0” .The variable bandwidth feature is incorporated by feeding back the amplifier (gain A) output through a current limiting resistor R to an auxiliary winding, ”l”, which is inductively coupled to the principal winding by the mutual inductance “m”. The receiver response is a function of the central frequency and the available feedback current. It is the latter that controls the system bandwidth as defined by the ratio of the highest to the lowest frequencies in the pass band, ω_H / ω_L. More precisely, $\omega_H / \omega_L = \omega_0 mA/2R = n^2$.

The frequency response for a variety of feedback settings as indicated by the parameter labels which correspond to values of ω_H / ω_L is shown below in Figure 2..

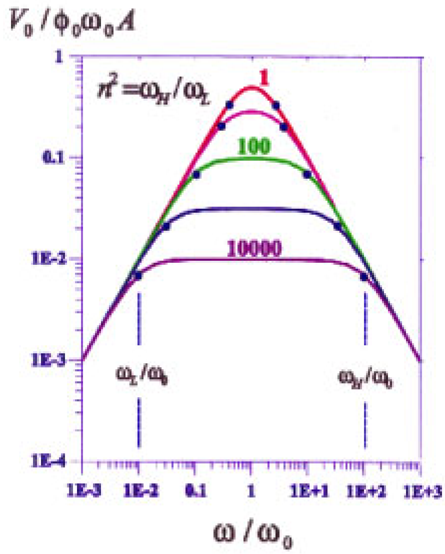

Figure 2. Frequency response of the wideband sensor.

Here we see how the sensor response varies, with the feedback parameter "n^2", as a function of the normalized frequency ω / ω_0. A feedback parameter value of unity corresponds to the classical critically damped induction receiver with no feedback. If ω_0, the resonant frequency of the receiver, is much greater than the frequency of peak target quadrature response then the sensor will in fact output a very close replica of the time derivative of the target signal. On the other hand, a sensor that is made to have a flat response over four decades of frequency by the application of massive feedback (n^2 = 10,000), will in fact have an output voltage that is closely proportional to the actual secondary magnetic field generated by the target.

Demonstration

To illustrate the effects of sensor bandwidth on the response of a typical target we consider a 37 mm diameter iron sphere. It has a relative magnetic permeability of about 200 and an electric conductivity of about ten million. The target, located 0.75 m below the surface is energized by a dipole transmitter of unit moment and detected with a collocated, concentric axial sensor. In this case the target is illuminated with a repetitive boxcar (rectangular) waveform of alternating polarity and 50% duty cycle. The fundamental frequency of about 870 Hz was specifically chosen to maximize the observable transient signal for the 37 mm spherical target. The effects of sensor bandwidth are shown below in Figure 3. When the unfiltered theoretical response of this target is compared with the observable filtered transient signal the effect of limited sensor bandwidth is apparent. In fact four decades of bandwidth, in this case from 40 Hz to 400 kHz are needed to properly record the observable target signal. The loss of two decades of bandwidth by increasing the high-pass frequency to 400 Hz and reducing the low-pass frequency to 40 kHz clearly results in a considerable distortion of the transient. Finally we note a complete change in the observable transient when a critically damped detector tuned to about 4 kHz is used. Here the initial, positive, part of the observed transient simply corresponds to the impulse response of the sensor. Only its amplitude is related to the target presence. A close inspection of the negative part of the transient signal however, will reveal that the decay rate of this portion of the transient signal is governed only by the properties of the target. In fact, as indicated by the negative sign, it is a replica of the time derivative of target signal.

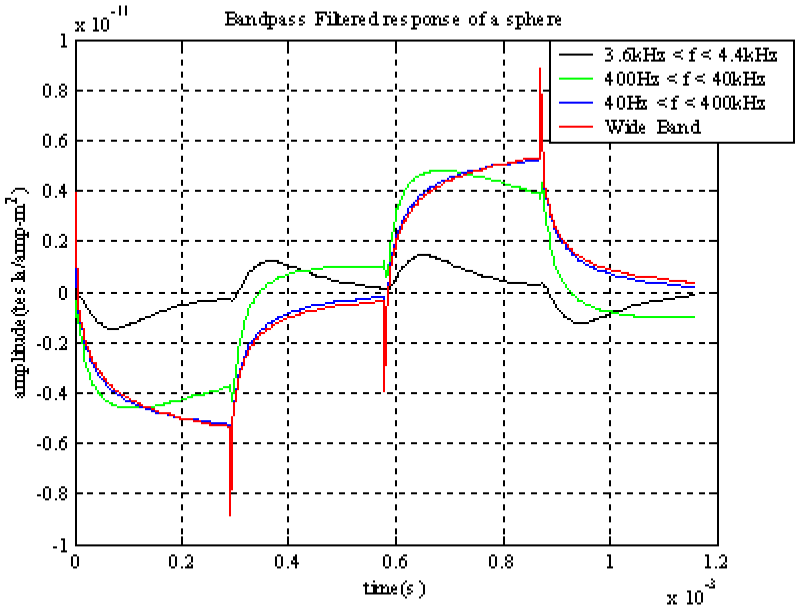

Figure 3. Effect of system bandwidth on the observable target signal

Summary and Discussion

We have shown that the received EM signal related to a particular target will be distorted to a degree that depends on the system bandwidth. It is likely that for a given range of targets and given ambient noise characteristics one can optimize the system bandwidth so as to maximize the observable signal to noise ratio. A sensor with four or more decades of flat frequency response is needed to record the secondary magnetic fields associated with the target. On the other hand, in some circumstances it may be more advantageous to use a conventional, tuned and critically damped dB/dt sensor.

Acknowledgement

This research was funded by the US Department of Defense under SERDP Project #UX1225.

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